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THE EFFECT OF
VARYING COMPRESSION PRESSURES
UPON THE
ECONOMY AND PERFORMANCE
OF A HOLMES
INTERNAL COMBUSTION ENGINE.

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A Thesis Submitted to
The Faculty of the Towne Scientific School
of
The University Of Pennsylvania
for the
Degree of Bachelor of Science
in
Mechanical Engineering.

by

R.H.Bradbury
J.B.Hopkins

June 1906

THE EFFECT OF VARYING COMPRESSION PRESSURES UPON THE ECONOMY AND PERFORMANCE OF A MODERN INTERNAL COMBUSTION ENGINE.

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3 D 26 Mech. Eng. Dept. B., Robert Hart & H., Joseph Strauss Internal combustion engines

INTRODUCTION

Increasing compression pressures and higher speeds have been synonomous with the development of the internal combustion engine , especially the automobile engine. The first crude engines of Lenoir and Hugon had no compression. Barnett's engine in England was the first attempt to compress the charge before exploding - about 1838. For a long time the importance of compression was not realized; the many experiments carried on resulting in the construction of engines with little or no compression. The first conception of the importance of high compression was had by Beau de Rocha in 1862 when he stated that high compression was one of the four requirements for good economy and best operation of any internal combustion engine.

In the practical developement of the internal combustion engine in the last 40 years the thermal efficiencies have gradually risen from 15% to a maximum of 35% chiefly due to the decreased combustion chamber and the resulting increased compression pressure. The pressures have been raised from zero to values as high as 120 pounds per square inch for practical use while at the bureau of

standards tests have been made in which the compression ratio was carried up to a value of 14 to 1, giving compression pressures of about 400 pounds per square inch. This refers, of course, to an engine operating on the normal Otto cycle.

Theoretically it can be proved that the Otto cycle efficiency is a function of the compression pressure and that it increases with an increase in compression. The equation $E=1-\frac{1}{r_c}$ is the result of the thermo-dynamic analysis of the Otto cycle. It shows that the greater r_c the higher the cycle efficiency, all other things being equal.

Since this theoretical knowledge has been known for a long time it seems correct to conclude that the increase in compression ratio has not been due to the results of experiments but that it has come about in spite of experiments. Designers have always had the criterion of more compression equals greater efficiency but the numerous practical difficulties which invariably arise when compression is increased without regard to other details of the engine have compelled them to modify the theories.

At the present time, however, this subject of increasing compression pressures is under active investigation. Recent tests have proved that no matter how high the compression ratio is raised

there is an increase in the efficiency so that this seems to give great promise of more power with less fuel and smaller engines. For by increasing the efficiency of an engine we get more power out of that engine since more of the energy of the fuel is utilized. Hence smaller engines can be built that will give power equal to that of the larger engines of to-day because the fuel charge can be smaller and we know that fuel charge governs the cylinder displacement.

It has also been discoverd in this connection that every fuel has a limiting value of compression pressure when employed in an engine, and that in the case of a low-limit fuel the allowable compression pressure of the engine is limited by this fact. Any attempt to run the engine above the limiting pressure as determined by the fuel will result in detonation or preignition. By adding certain other fuels and chemicals known as dopes or stabilizers such as tetraethyl-lead, ethyl iodide and aniline in small portions to ordinary gasoline the limiting compression pressure can be raised considerably and more power can be obtained without the tendency of the engine to knock or detonate.

Another factor, as regards compression, is the shape of the combustion chamber. The Ricardo head, of which a

diagramatic view is shown on page11 is an example of a combustion chamber which is designed to cause a swirling of the gases at the time they are compressed. This causes quicker flame propagation which results in moreaccurate timing and therefore in increased power. Several of the modern automobile engines have this type of combustion chamber.

There are then, these phases of engine developement which are closely related to the proposition of getting higher efficiency and more power by increased compression pressures;namely, special fuels which will not detonate or preignite at the higher compression pressures, specially shaped combustion chambers which not only cause more positive ignition but prevent preignition by reason of the rapid motion of the gases, and, finally, higher speed engines.

The object of this investigation is to determine the effect of varying compression pressures upon the fuel economy and general performance of a modern automobile engine. Presumably the modern automobile motor has been developed to the highest possible degree, all things being condsidered. This presumption is based on the fact that competition would very soon eliminate any engine which was not so developed. Therefore, any alteration in the motor as designed at present which

increases the compression alone should result, according to theory, in increased fuel economy but according to the above assumption, in decreased performance due to the knocking caused by preignition or detonation.

The importance of this investigation lies in its relevancy to modern automotive engine developement. While,on the one hand its results support the fundamental theory that increased compression results in increased efficiency, on the other it demonstrates the practical difficulties in the mere superficial action of increasing the compression pressure. There is much reason to believe that the most promising direction in which to look for improvement in overall economy and efficiency is towards increased compression pressures; hence any investigation which sheds even a little light on this most important phase of automobile engineering is important and worth while.

"Fuel economy" as determined in this investigation is the regular miles per gallon for various speeds. It was measured in accordance with the S.A.E. Standard Car Performance Tests. "General Performance" means specifically the capacity to accelerate, to climb hills and to travel at high speed and generally

to perform in such a way that there are no detonation knocks, over-heating effects or any other harmful symptoms which would be noticable to one who is a critical observer of such faults.

DESCRIPTION OF ENGINE AND CAR WHICH WAS USED IN THIS INVESTIGATION.

The car used in this investigation was a 1926 model Big Six Studebaker sedan. Its mileage was 2000 when the investigation was started.

ENGINE SPECIFICATIONS

Bore 3.875

Stroke 5.00

Displacement 354 cu.in.

S.A.E.H.P.Rating 36

Timing order 1-5-3-6-2-4

Normal compression ratio 4.22

Carburetor $1\frac{1}{2}$" B.&B.

GEAR TRANSMISSION RATIOS

High 1 to 1

Intermediate 1.96 to 1

Low 3.34 to 1

Reverse 4.16 to 1

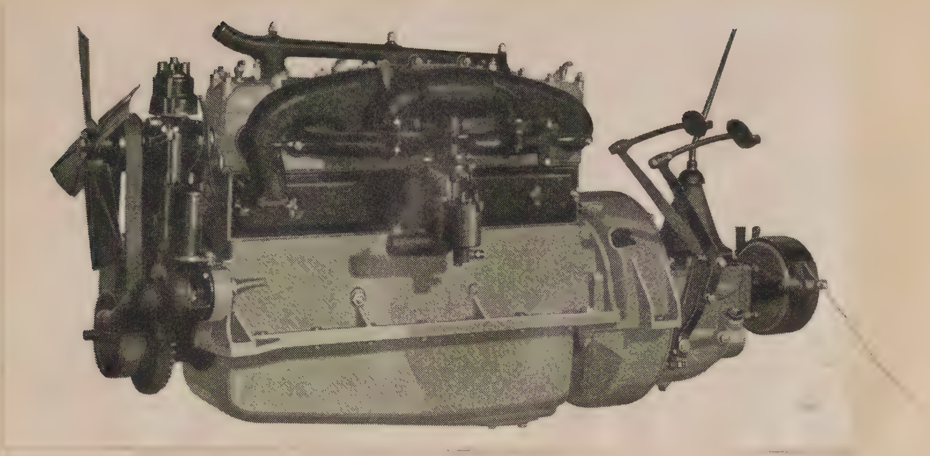
Pinion teeth 11

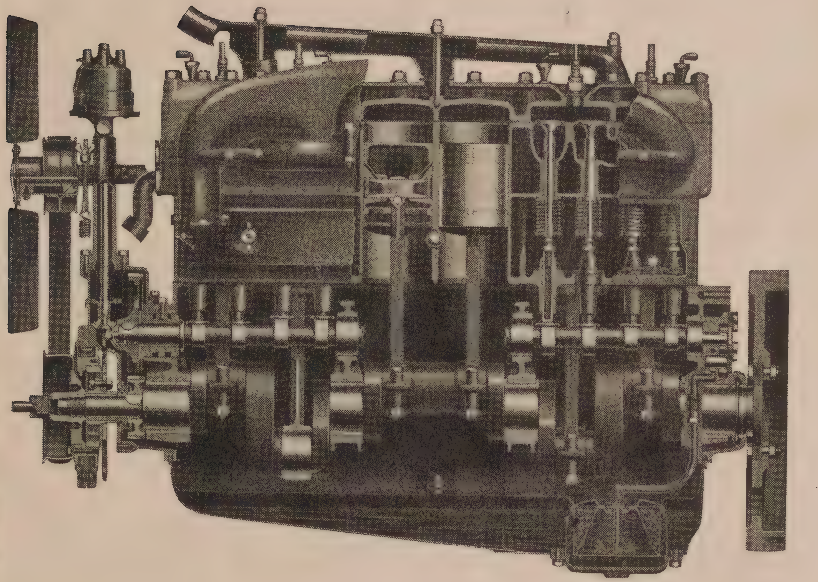
Pinion teeth 12-13

Ring gear teeth 48-49

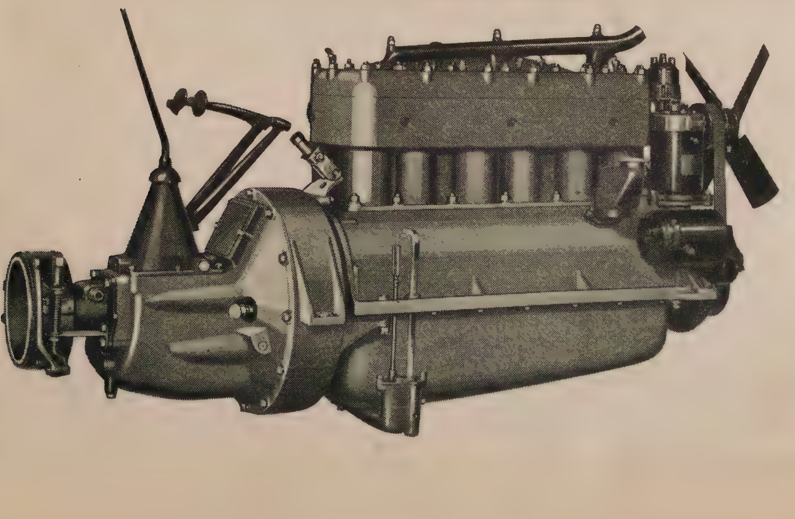
Ratios 4.08, 4.36, 3.69

VIEWS OF ENGINE.



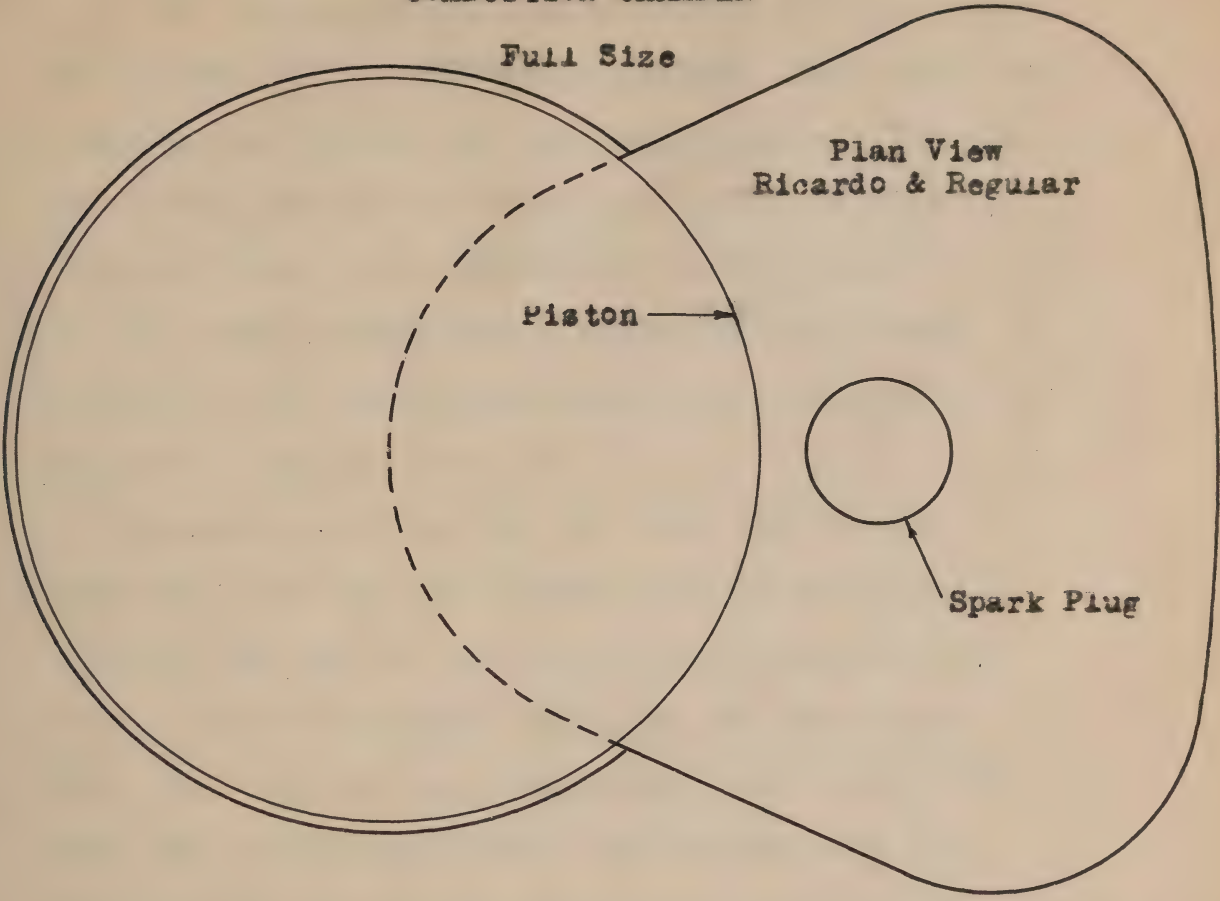


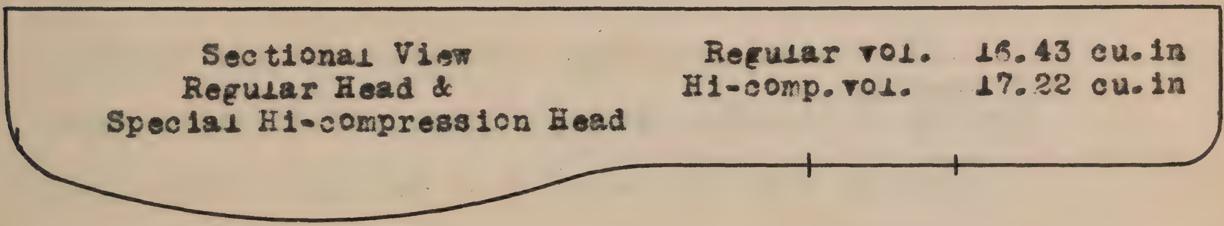
Cross section of Big Six Engine.



COMBUSTION CHAMBER

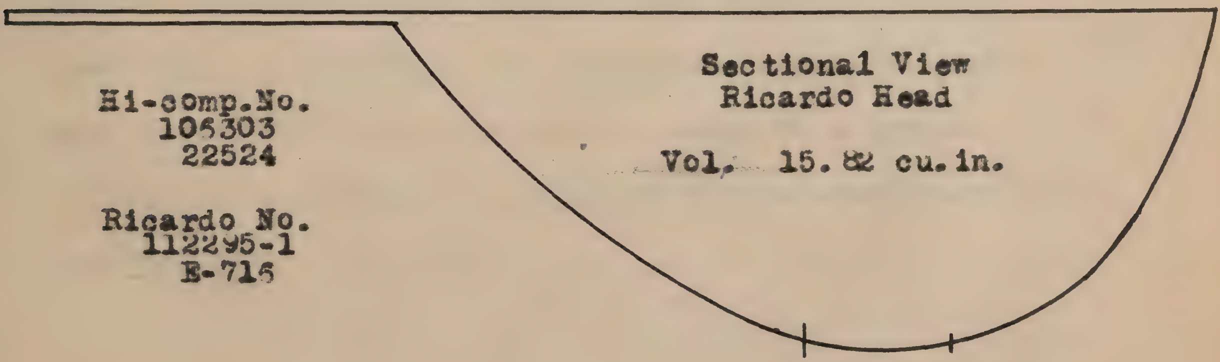
Full Size





Hi-comp.No.
106303
22524

Ricardo No.
112295-1
E-716



PREPARATION FOR TEST

The valves were all in good condition so there was little or no compression leakage. The carbon was removed just before the runs were started. The oil and grease were not altered in any way so that running conditions were maintained in that respect. All the spark plugs were cleaned and functioned properly. The gas used throughout the test was Atlantic - sp.gravity 0.75.

To prepare the car for the test the regular gasoline line from the vacuum tank to the carburetor was removed and a copper gas line was run from a pair of weighing tanks on the dash board thru the floor to the carburetor. The vacuum line from the intake manifold to the vacuum tank was removed and the hole in the intake manifold was plugged up. The weighing tanks were simply two square one-gallon capacity tanks mounted on a board and inter-connected by a three-way cock in such a way as to allow either one of the tanks to feed gasoline, by gravity, to the carburetor. One tank was connected to the system by means of a ground-joint union so that it could be removed easily to be weighed.

Four different compression pressures were obtained by means of extra gaskets and two special heads which were furnished by the Studebaker Corporation. No.1 pressure was the normal pressure obtained by using the standard head and a single gasket. This pressure was about 90 pounds per square inch absolute (75.3 guage). No.2 pressure was that obtained by inserting three gaskets under the normal head (65.9 pounds guage). No.3 pressure was that obtained when a special high compression head was used (79.9 pounds guage). No.4 pressure was 83.6 pounds guage, obtained by using a Ricardo head.

These pressure values are all calculated from volumetric measurements of the clearance spaces, assuming n 1.32 and p 13.5 pounds. The pressures were also measured directly by an Okill pressure guage. This guage method of measuring pressures in this investigation only served to readily show that any new pressure was different enough from the others to warrant our making all the runs involved under the new conditions. The gauge results are: No.1-73# No.2-66# No.3-81# No.4-85#.

At first each cylinder pressure was tested but the compression pressure for the different cylinders was so nearly equal that thereafter the reading for

one cylinder was deemed accurate enough to serve as a guide for the new pressure conditions in all the cylinders.

To change the compression ratios it was, of course, necessary to change the heads. This was not as difficult as it seems at first. There were only 28 bolts on the head and 3 on the water manifold which had to be removed each time; also the spark plugs and priming cups. Cup grease was used on both sides of all gaskets, no shellac. It took about one hour to change the heads and again as long to tighten the new head properly. It is important that the engine be well warmed after a new head has been put on so that all the slack in the studs can be taken up, otherwise there will be compression loss around the gasket. A new gasket was used each time the head was changed.

The fuel economy runs were made on the Potstown Pa. automobile race track; a mile track covered with a thin layer of asphalt. This was an ideal course for this test as there was no interference during any of the runs.

After a preliminary run around the track during which the throttle was adjusted to give the desired speed (as indicated by the speedometer) a run was made at that speed. When the starting line was reached the

three-way cock was used to disconnect the manoeuvering tank and to run on the weighing tank; the time was taken with a stop-watch. During a 2 mile run the throttle was kept constant; the spark was, therefore, also practically constant since the engine was equipped with an automatic spark control and the track was quite level. At the end of the run the time was taken and the weighing tank was disconnected as the car crossed the finish line. The weighing tank and its contents was then removed and weighed on scales which were set up on the ground at the finish line.

CALCULATIONS

$p_1v_1^n = p_2v_2^n$ $p_2 = p_1\left(\frac{v_1}{v_2}\right)^n$ = $p_1\left(r_c\right)^n$

Assume n = 1.32 and $p_1 = 13.5$ #

No.1 Pressure (normal conditions)

Volume of combustion chamber 283 c.c.-----17.22 cu. in.

Gasket thickness $\frac{3}{32}$"

$\frac{\pi \times 3.875^2 \times 3}{4 \times 32}$ = --------------- 1.10 cu. in.

18.32 total

Displacement $\frac{\pi \times 3.875^2 \times 5}{4}$ = ----------59.00 cu. in.

v_1 = total volume -------------------------77.32 cu. in.

$r_c = \frac{v_1}{v_2} = \frac{77.32}{18.32}$ = ---------------------- 4.22

% clearance ---------------------------- 23.7

log p_2 = log 13.5 + 1.32 log 4.22

= 1.1302 + 1.32 × .625 = 1.9552

p_2 = 90.0 #/□" absolute.

No.2 Pressure (normal head 3 gaskets)

v_2 = 17.22 + 3 × 1.10 ------------------- 20.52 cu. in.

$v_1 = v_2$ + displacement ---------------- 79.52 cu. in.

r_c = ---------------------------------- 3.88

% clearance = --------------------------- 25.8

p_2 = 80.6 #/□" absolute.

No. 3 Pressure (High compression)

v_1 --------------------------------76.53 cu. in.

v_2 --------------------------------17.53 cu. in.

r_c -------------------------------- 4.37

% clearance ---------------------- 22.9

p_2 = 94.6 #/□" absolute.

No. 4 Pressure (Ricardo head)

v_1 -------------------------------75.92 cu. in.

v_2 -------------------------------16.92 cu. in.

r_c ------------------------------- 4.5

% clearance ---------------------22.3

p_2 = 98.3 #/□" absolute.

DATA SHEET NO.1

Fuel Economy Run NO.1 Compression(75.3)

Length of Lap 2 miles.

Approx. speed mi./hr.	8	12	22	25	27	37
Time- min.	14.54	10.14	5.45	5.04	4.42	3.26
Velocity mi./hr.	8.25	11.81	22.05	24.85	27.15	36.80
Wgt. fuel & tank-start.	14.43	13.07	11.73	10.51	13.55	12.25
Wgt.fuel & tank-end.	13.07	11.73	10.51	9.28	12.26	10.81
Wgt. fuel used-lbs.	1.36	1.34	1.22	1.23	1.29	1.45
Quantity of fuel-gal.	.214	.211	.192	.194	.203	.228
Mi./gal.	9.34	9.47	10.33	10.31	9.82	8.74

Fuel Economy Check Run

Approx. speed mi./hr.	8	15	20	25	30	35
Time-min.	14.27	7.95	6.28	4.84	3.82	3.34
Velocity mi./ hr.	8.43	15.10	19.10	24.80	31.42	36.00
Wgt. fuel & tank-start.	14.48	13.01	11.70	14.53	13.22	11.88
Wgt.fuel & tank-end.	13.01	11.70	10.42	13.22	11.88	10.53
Wgt. fuel used-lbs.	1.47	1.31	1.28	1.31	1.33	1.35
Quantity of fuel-gal.	.231	.206	.201	.206	.210	.212
Mi./gal.	8.60	9.64	9.88	9.62	9.50	9.36

DATA SHEET NO.2

Fuel Economy Run No.2 Compression(65.9)

Length of Lap 2 miles.

Approx. speed mi./hr.	8	15	20	25	30	35
Time-min.	14.23	8.03	6.33	5.01	3.88	3.34
Velocity mi./ hr.	8.44	14.97	19.00	24.00	31.00	35.90
Wgt. fuel & tank start.	14.31	12.81	11.42	14.04	12.71	11.38
Wgt.fuel & tank end.	12.81	11.42	10.14	12.71	11.38	10.02
Wgt.fuel used-lbs	1.50	1.39	1.28	1.33	1.34	1.36
Quantity of fuel-gal.	.236	.219	.201	.210	.211	.214
Mi./gal.	8.44	9.10	9.87	9.53	9.46	9.34

Fuel Economy Check Run

Approx. speed mi. /hr.	8	12	20	25	30	35
Time-min.	14.58	10.15	5.47	5.04	4.36	3.08
Velocity mi./hr.	8.23	11.81	21.92	23.90	27.50	38.90
Wgt.fuel & tank start	14.25	12.88	11.54	10.33	14.41	13.13
Wgt.fuel & tank-end.	12.88	11.54	10.33	9.11	13.13	11.71
Wgt.fuel used-lbs.	1.37	1.34	1.20	1.21	1.28	1.41
Quantity of fuels-gal.	.216	.211	.189	.191	.201	.222
Mi./gal.	9.24	9.41	10.44	10.39	9.88	8.94

DATA SHEET NO.3

Fuel Economy Run No.3 Compression (79.9)

Length of Lap 2 miles

Approx. speed mi./hr.	8	12	18	25	30	38
Time-min.	15.31	9.85	6.89	4.62	4.12	3.11
Velocity mi./hr.	7.85	12.20	17.43	26.10	29.20	38.60
Wgt.fuel & tank-start	15.97	14.75	13.55	12.40	15.95	14.77
Wgt.fuel & tank-end.	14.75	13.55	12.40	11.16	14.77	13.55
Wgt-fuel used-lbs.	1.23	1.20	1.15	1.14	1.18	1.22
Quantity of fuel-gal.	.194	.189	.181	.179	.186	.192
Mi./gal.	10.31	10.53	11.43	11.45	11.42	10.40

Fuel Economy Check Run

Approx. speed mi./hr.	8	12	18	25	30	38
Time-min.	15.22	9.62	6.79	4.84	3.80	3.09
Velocity mi./ hr.	7.90	12.61	17.70	24.80	31.60	38.81
Wgt.fuel& tank-start.	15.47	14.26	13.05	11.94	14.55	13.37
Wgt.fuel & tank-end.	14.26	13.05	11.94	10.85	13.37	12.16
Wgt.fuel used-lbs.	1.21	1.19	1.11	1.09	1.17	1.21
Quantity of fuel-gal.	.191	.187	.175	.172	.184	.191
Mi./ gal.	10.43	10.60	11.38	11.58	10.78	10.46

DATA SHEET NO.4

Fuel Economy Run No.4 Compression (83.6)

Length of Lap 2 miles

Approx. speed mi./ hr.	9	15	18	25	30	38
Time- min.	13.04	7.69	6.72	4.81	3.78	3.15
Velocity mi. / hr.	9.21	15.60	17.87	24.95	31.80	38.10
Wgt. fuel & tank- start	13.55	12.18	14.63	13.47	12.43	11.34
Wgt. fuel & tank- end	12.18	10.98	13.47	12.43	11.34	10.12
Wgt. fuel used-lbs.	1.37	1.20	1.16	1.04	1.09	1.22
Quantity of fuel- gal.	.216	.189	.183	.164	.172	.192
Mi./ gal.	9.25	10.55	10.90	12.10	11.60	10.40

Fuel Economy Check Run

Approx. speed mi./ hr.	9	15	18	25	30	38
Time- min.	13.12	7.43	6.63	4.77	3.69	3.13
Velocity mi./ hr.	9.14	16.15	18.10	25.10	32.50	38.31
Wgt. fuel & tank- start	15.16	13.89	12.73	11.63	14.25	13.16
Wgt. fuel & tank- end	13.89	12.73	11.63	10.58	13.16	11.97
Wgt. fuel used-lbs.	1.26	1.16	1.10	1.04	1.09	1.19
Quantity of fuel- gal.	.198	.183	.173	.164	.172	.187
Mi./gal.	9.97	10.86	11.43	12.15	11.63	10.61

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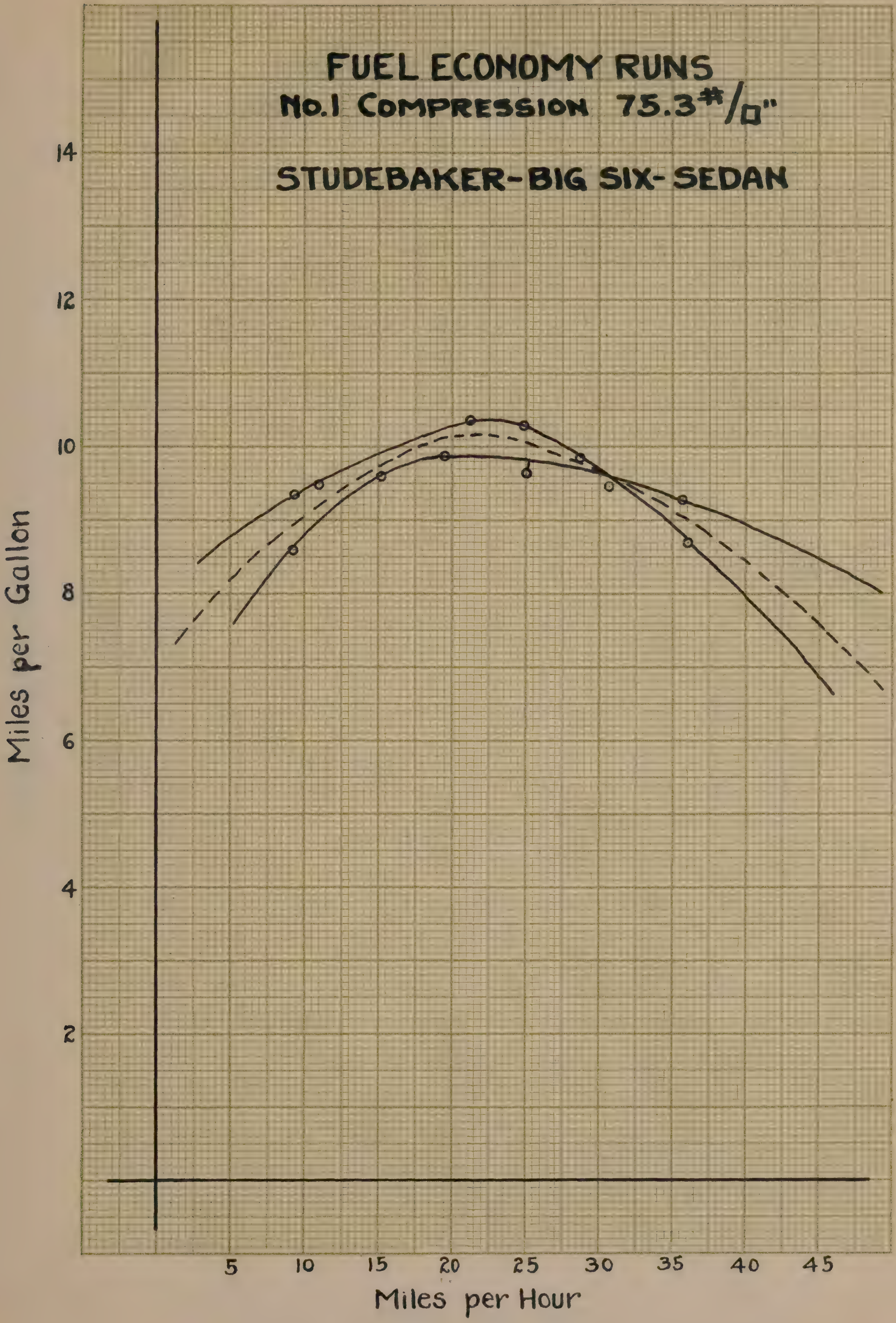

FUEL ECONOMY RUNS
No.1 COMPRESSION 75.3#/□"

STUDEBAKER-BIG SIX-SEDAN

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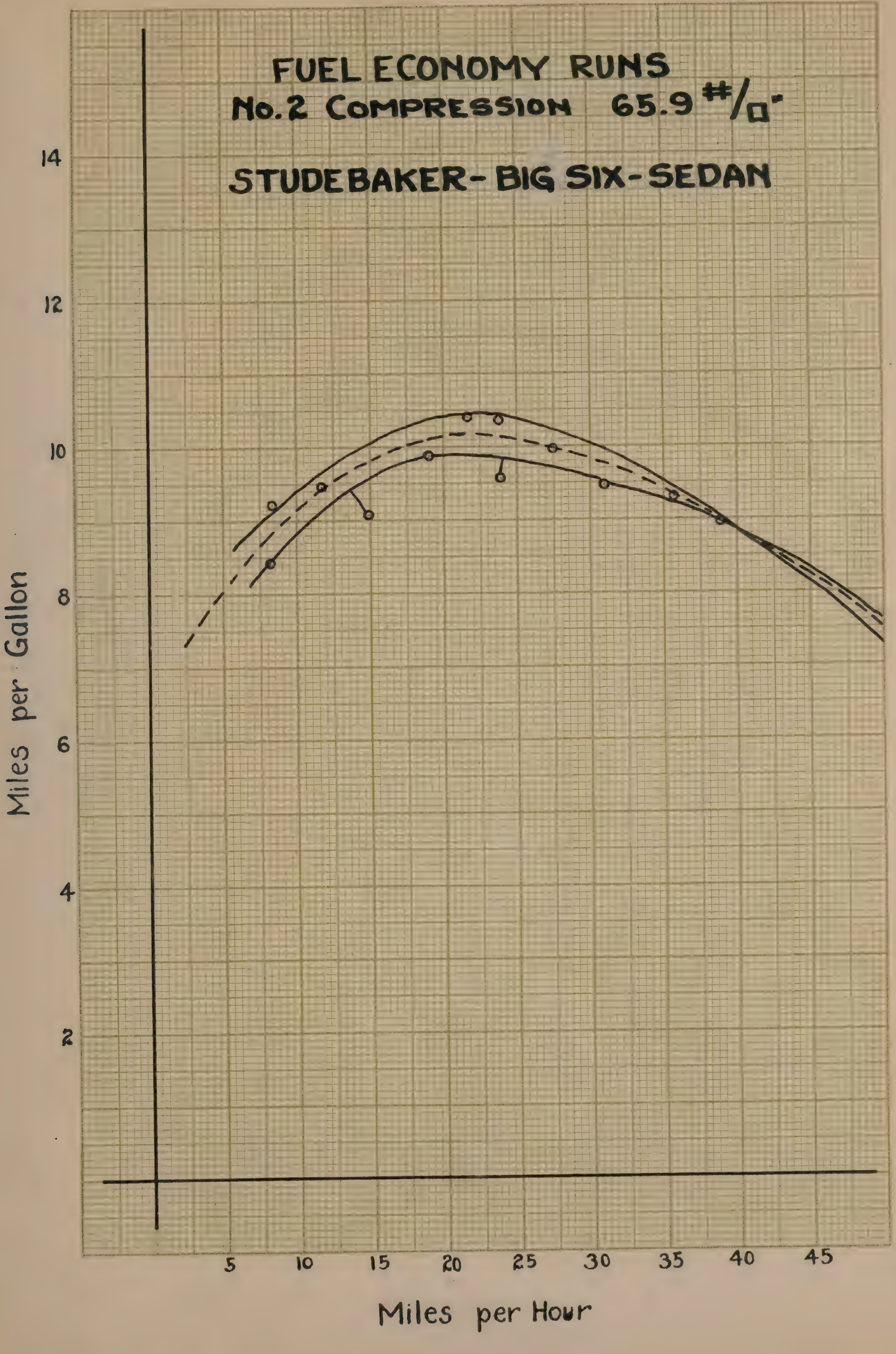

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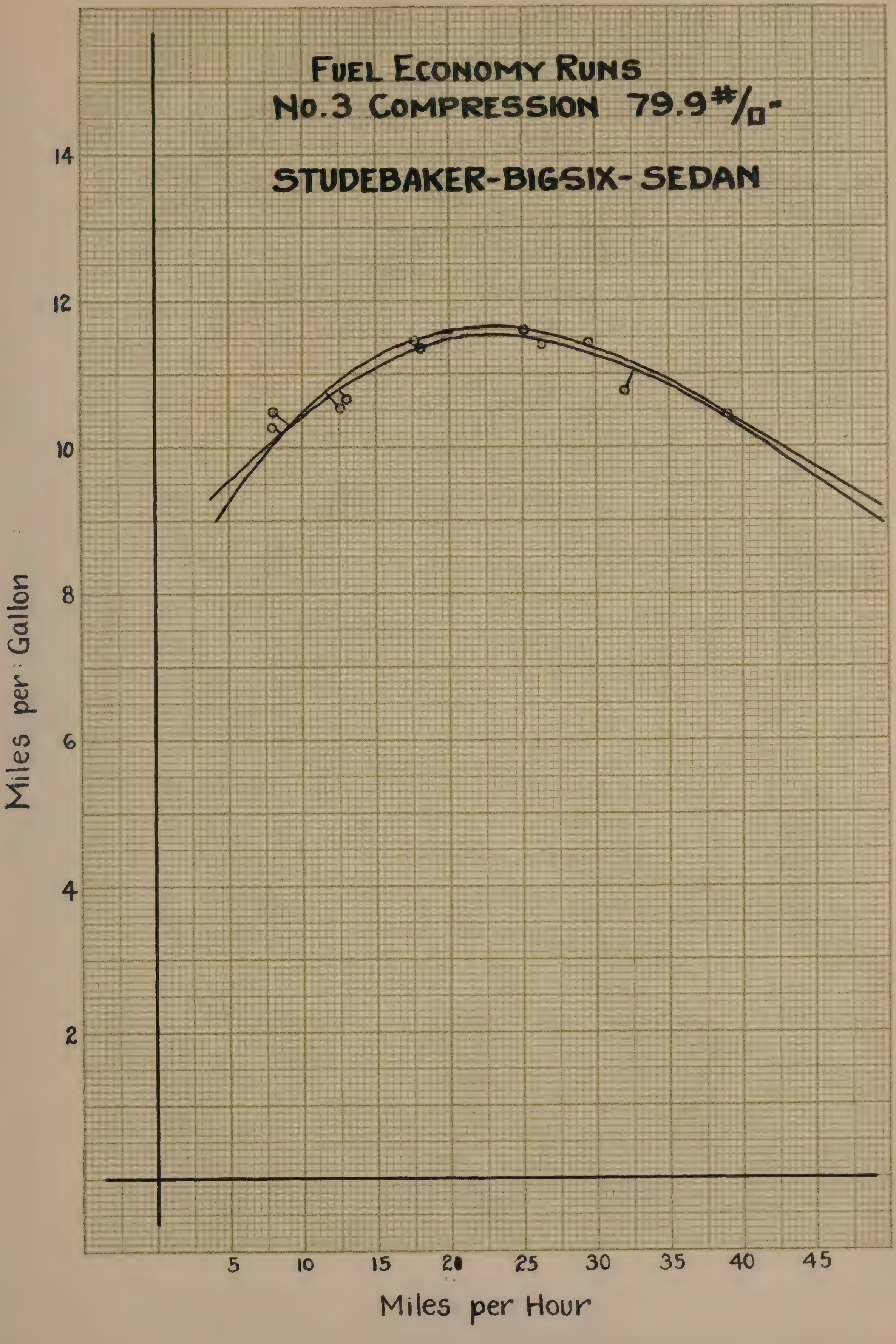

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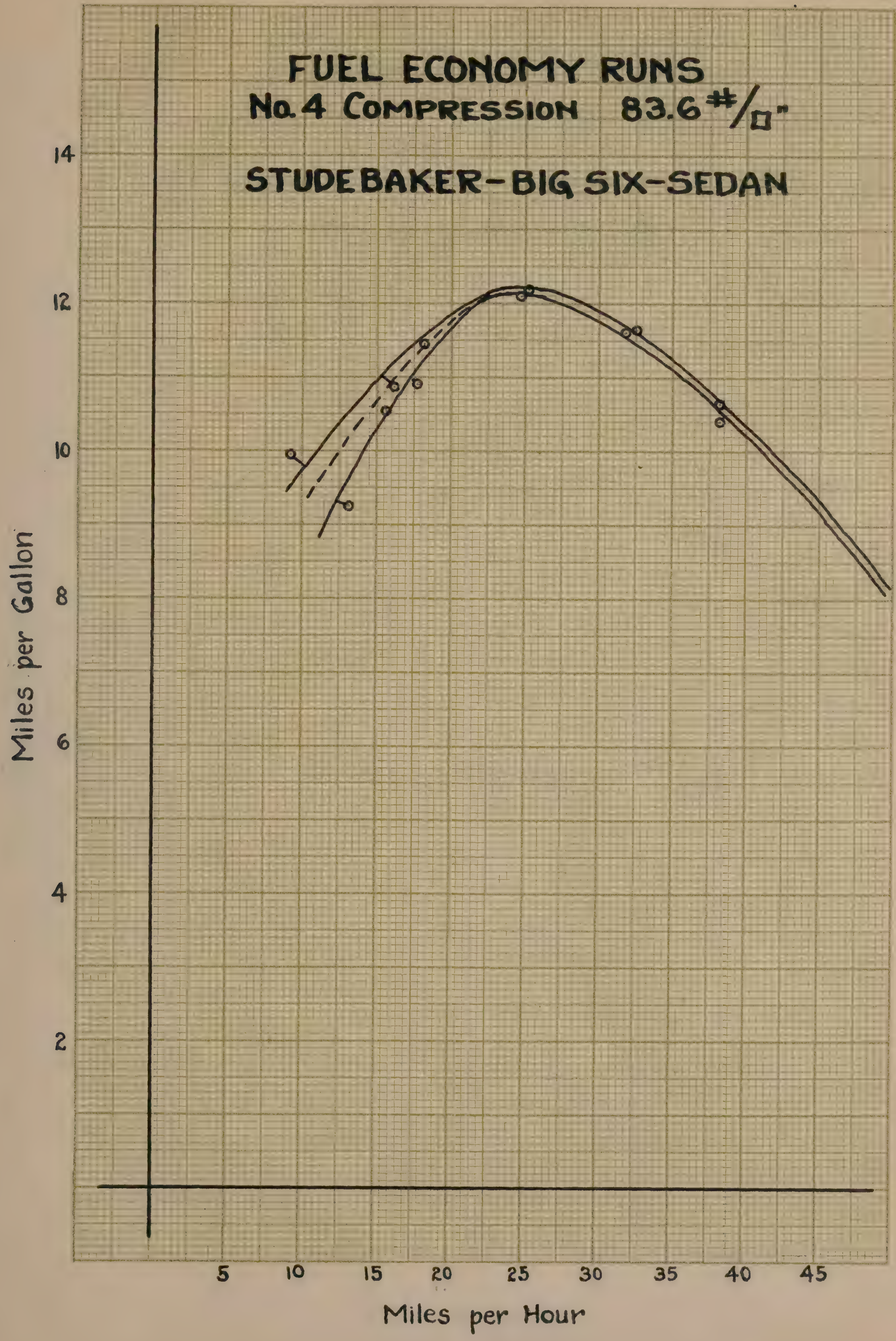

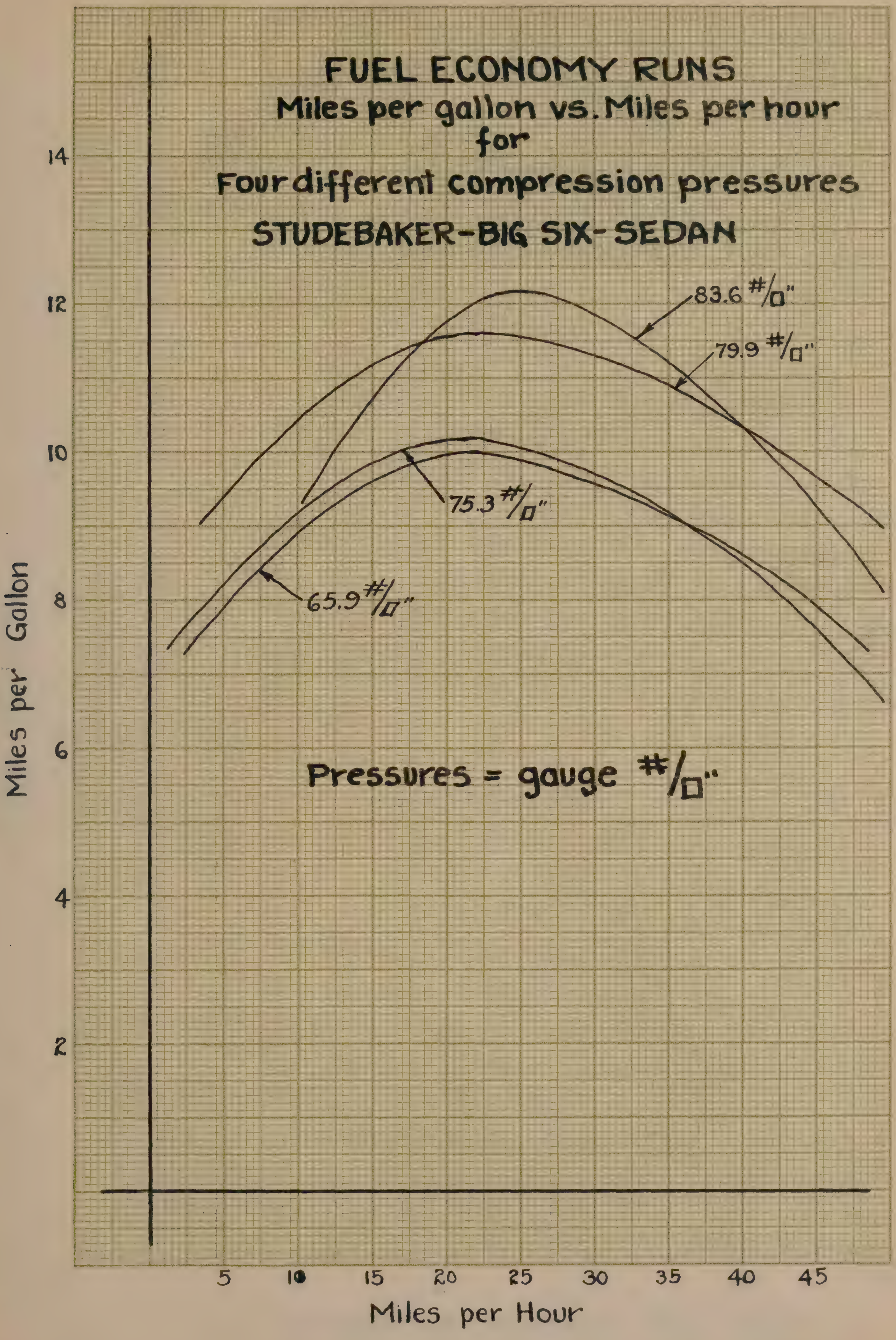
FUEL ECONOMY RUNS
Miles per gallon vs. Miles per hour
for
Four different compression pressures
STUDEBAKER-BIG SIX-SEDAN
83.6 #/□"
79.9 #/□"
75.3 #/□"
65.9 #/□"
Pressures = gauge #/□"
14
12
10
8
6
4
2
Miles per Gallon
5
10
15
20
25
30
35
40
45
Miles per Hour

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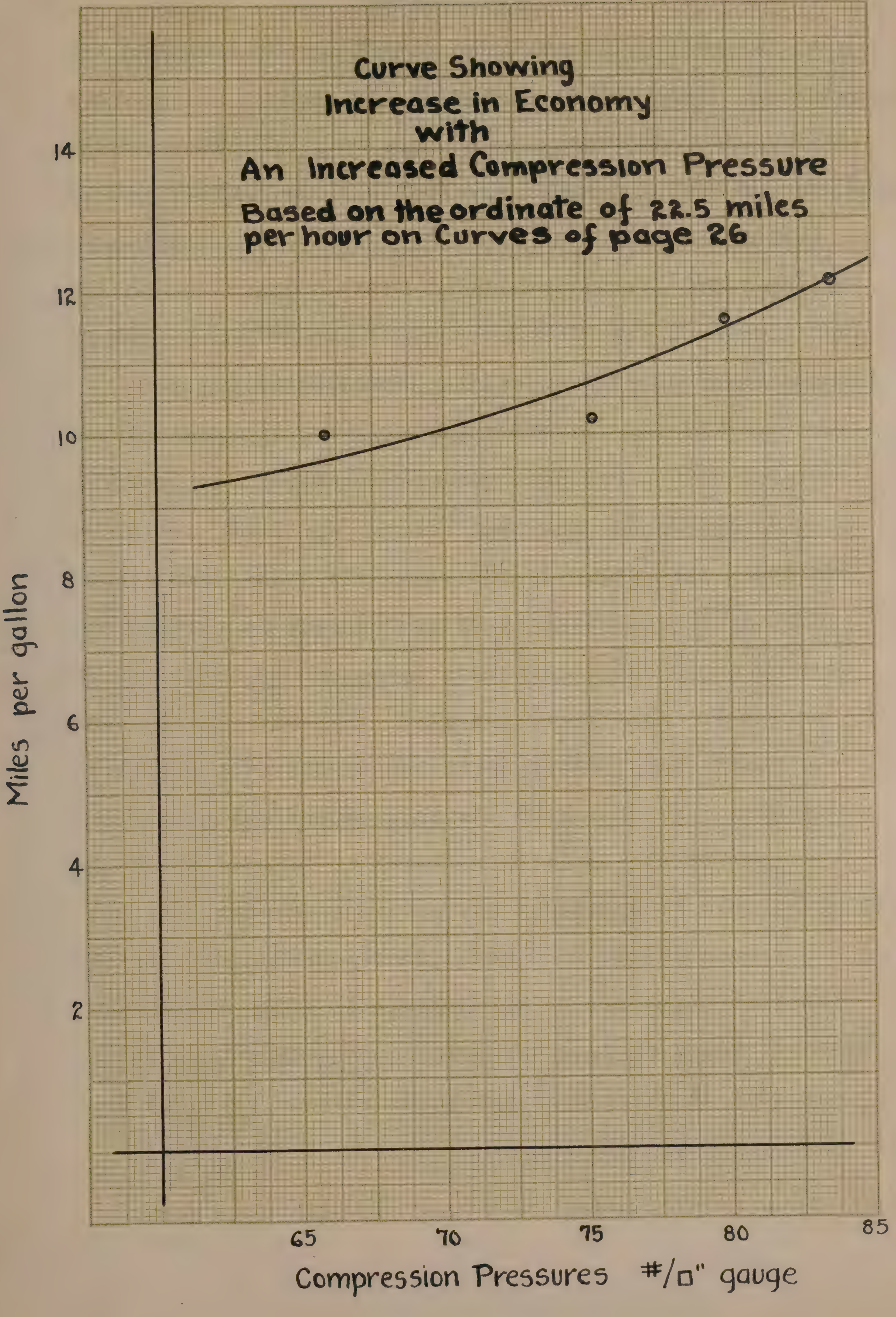

Curve Showing
Increase in Economy
with
An Increased Compression Pressure
Based on the ordinate of 22.5 miles per hour on Curves of page 26

CONCLUSIONS

The accuracy of the fuel economy runs was effected adversely by the weather and by reason of the fact that Atlantic gasoline from one lot was not used throughout the tests. Always keeping in mind, however, that the fuel economy runs were just a part of the test and not its main purpose, neither of these factors introduced errors great enough to change any of the basic results of the investigation.

As far as performance goes we have decided that this particular engine is greatly improved when the compression pressure is decreased slightly from that which obtains normally. With the regular head and one gasket(normal conditions) there was invariably a pronounced knocking and bucking at speeds from 10 miles an hour down. The first effect of decreased compression which was noticed was that all knocking disappeared and that the engine performed more evenly and more quietly. The effect of increasing the compression was to intensify the knocking which occured at normal conditions. So it was concluded that this engine was operating at a compression pressure which was too high for best performance. Practically, this conclusion led to permanent decrease in the compression by putting two gaskets under the head. Many miles of running since the test seems to indicate

that this method is a simple and effective means for getting the proper compression pressure for this engine.

The important conclusion drawn from the results of this investigation is that increased economy should not be the ultimate aim of modern engine designers when it comes to a question of increasing compression ratios but rather increased economy plus increased or equal performance. And this involves the re-design of the whole engine - the net result being higher rotative speeds, smaller pistons and hence smaller engines, and increased gear ratios.

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